FINAL REPORT

A DEMONSTRATION AREA ON ECOSYSTEM RESPONSE TO WATERSHED-SCALE BURNS IN GREAT BASIN PINYON-JUNIPER WOODLANDS

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OVERVIEW

Since European settlement of the Great Basin about 130 years ago, pinyon and juniper have exhibited significant increases in both area and stand densities. Progressive increases in woody and fine fuel loads coupled with the invasion of a highly flammable annual grass, cheatgrass, have resulted in dramatic increases in fire frequency, severity and size in the woodlands. To prevent the widespread deterioration of the woodlands and their associated communities, it is necessary to implement proactive fuels management programs prior to stand closure and before cheatgrass dominance. This project developed a demonstration watershed in the central Great Basin for illustrating both the feasibility and ecological effects of large-scale prescribed fire on pinyon-juniper dominated ecosystems to managers, researchers, and the public. The Demonstration Watershed is a collaborative effort between the USDA Forest Service, Rocky Mountain Research Station and Humboldt-Toiyabe National Forest, and the Nevada Bureau of Land Management. It is linked to a second JFSP Project on "Effect of Fire and Rehabilitation Seeding on Sage Grouse Habitat in the Pinyon-juniper Zone" (JFSP # 01B-3-3-01). In addition, the Demonstration Watershed serves as one of the study locations for a third JFSP Project, "Changing Fire Regimes, Increased Fuel Loads, and Invasive Species: Effects on Sagebrush Steppe and Pinyon-Juniper Ecosystems" (JFSP #00-1-1-03) and is being used for a collaborative National Fire Plan Study on "Carbon and Nitrogen Balances in Pinyon-Juniper Watersheds."

The original objectives for the Demonstration Watershed included: (1) Illustrate the use of a watershed-scale approach to conducting prescribed burns; (2) Determine the changes in fuel loads that occur with increasing stand densities of pinyon and juniper; (3) Evaluate the recovery thresholds and successional trajectories for vegetation communities that have different stand densities of pinyon and juniper, i.e., low, intermediate, and high tree densities, and that occur at different elevations within the watersheds; (4) Examine the influence of differences in stand density and topographic position on soil properties that influence recovery potential and soil erosion; (5) Evaluate the effects of large-scale prescribed burn projects on stream channels, sedimentation and water quality. (6) Examine the effects of the burn on the species richness and occurrence of taxa shown to exhibit quantifiable responses to similar disturbances, i.e., butterflies. Four research burns (2 to 6 hectares each) were conducted in spring 2002, and an additional 900 acres were treated within the watershed in spring 2004. Data on stand densities, fuel loads, understory vegetation, and soil and vegetation responses from the research burns were collected in 2002 through 2004. These are resulting in one Master's thesis on the effects of stand density and elevation on tree and understory fuel loads, one Master's thesis that examines the vegetation response over the three years following the burn, two submitted manuscripts on soil infiltration response, and soil chemical response, and one Master's thesis that integrates all of the soils data. Because of the delay in conducting the large-scale burns and below average precipitation in the central Great Basin during much of the study, it has not been possible to collect data on stream channels, sedimentation and water quality as initially planned. However, the stream cross-sections and instruments are in place and we will be able to examine any changes in the stream channels or water quality given higher precipitation in future years. Data on an important taxa in semi-arid, intermittent systems, butterflies, has been collected from 2000 through 2004, and has been coupled with existing data on the watersheds in the region to produce a Master's thesis and numerous important and useful articles. Yearly tours of the Demonstration Watershed are held that are attended by 60 or more individuals, and the area is being used for class field trips and fuels management training. The data from the Demonstration

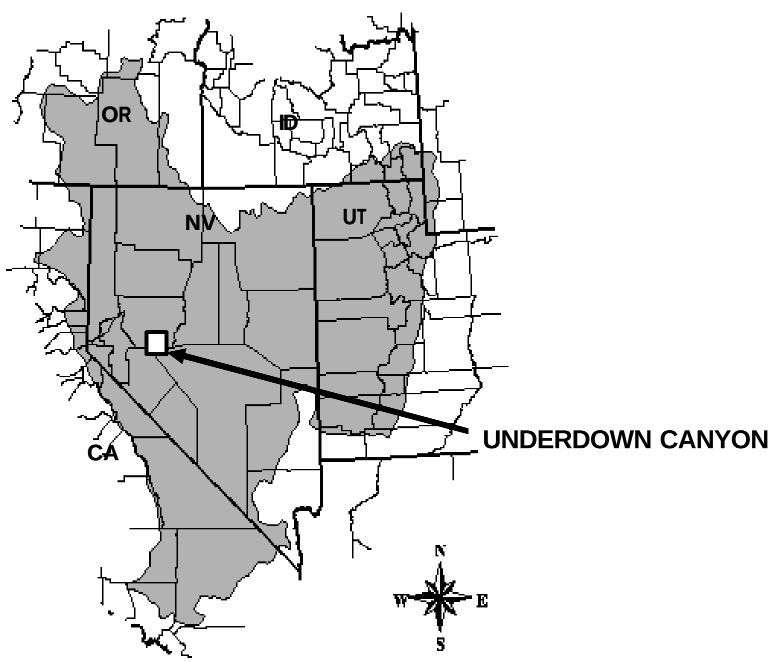
Watershed are being combined with linked JFSP projects and used to develop guidelines for evaluating the effects of increases in tree stand density and cover on vegetation community and soil response to prescribed burns.

The primary findings from the initial research on the Demonstration Watershed are summarized in the sections that follow. Each section represents one of the "Deliverables" in the original proposal. Much of the information presented has been extracted from existing reports, abstracts, or manuscripts. There will be some overlap with the linked JFSP Project on "Effect of Fire and Rehabilitation Seeding on Sage Grouse Habitat in the Pinyon-juniper Zone."

DELIVERABLES

A Demonstration Watershed of the Feasibility and Benefits of Watershed-Scale Burns

The Demonstration Watershed was established as a collaborative effort between the USDA Forest Service, Rocky Mountain Research Station and Humboldt-Toiyabe National Forest, and the Nevada Bureau of Land Management. It is located in Underdown Canyon (39.1511°N 117.3583°W) in the Shoshone Mountain Range on the Humboldt-Toiyabe National Forest (Austin Ranger District) in Nye and Lander Counties, Nevada. Riley Canyon, a neighboring watershed serves as a control. The geology of the watersheds consists of welded and non-welded silica ash flow tuff, and the soils developed on the alluvial fans used for the research burns are classified as Coarse loamy mixed frigid Typic Haploxerolls. Average annual precipitation ranges from 23 cm at the bottom to 50 cm at the top of the drainage and arrives mostly as winter snow and spring rains. Both watersheds have streams which are ephemeral during most years.



The original study was developed to examine both watershed-scale and stand/community-scale effects of the burn treatment. Studies of the effects of the burns on stream channels and water quality and also on butterfly taxa were designed to be examined at the watershed-scale. Studies of fuel loads and of vegetation and soil responses were designed to be evaluated at the community-scale. For the community-scale studies, three pairs of study sites (n=6) were located on north facing alluvial fans in June 2000 at elevations of 2073, 2103, 2195, and 2225; two sites were at 2347m. The fans range from two to six hectares in size. One of each pair of fans received the burn treatment, while the other served as a control. To evaluate the effects of burning over the elevational gradient, three macroplots ($0.1ha^2$) with intermediate tree densities were located on all burn and control sites. To examine the effects of burning on plots with different tree cover and fuel loads, three high tree cover and three low tree cover macroplots also were located at the mid-elevation sites (2195 and 2225m). Tree covers average 20% for low cover plots, 38% for intermediate cover plots and 78% for high tree cover plots. The community-scale burns were conducted in spring 2002 (May 11-14) by interagency fire crews. Despite fairly moist conditions at the time of the burn, every attempt was made to obtain uniform burn conditions. The community-scale burns were designed to be a part of larger watershed-scale burns. However, due to a restrictive burn window and concerns over potential escape, only the smaller-scale burns were conducted in 2002. Because of high winds and an inability to obtain the necessary conditions for the burns, the watershed-scale burns were again postponed in 2003. During the third try in 2004, an additional 900 acres were treated resulting in a mosaic of burned and nonburned conditions within the watershed.

Mean soil temperatures of community-scale burns measured with heat sensitive paints on metal strips using methods in Korfmacher et al. 2002.

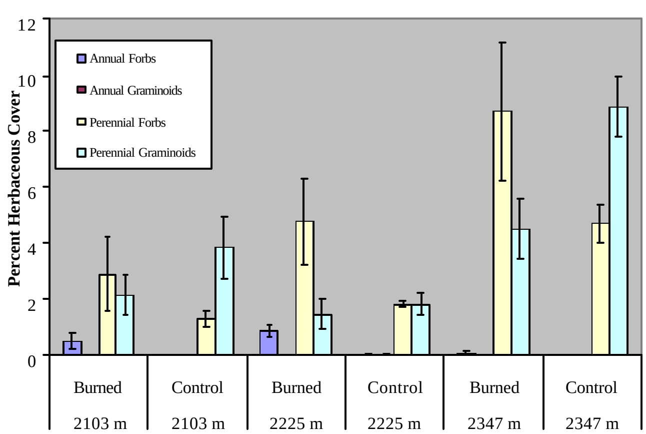
Microsite	Avg. temperature (°C)
------------------surface--------------------	
Interspace	206.1
Under shrub	369.4
Under tree	303.9
--------------------2 cm---------------------	
Interspace	39.5
Under shrub	86
Under tree	76.8
--------------------5 cm---------------------	
Interspace	39.5
Under Shrub	39.5
Under Tree	43.9

Effects of Stand Cover and Elevation on Vegetation Response to Fire

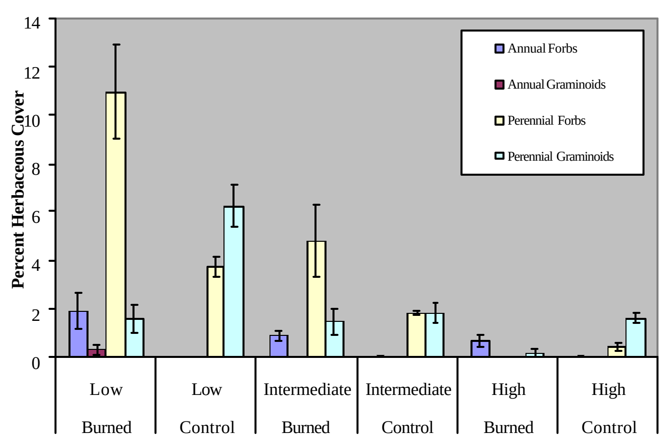
The effects of elevation (community type) and tree cover on the vegetation recovery of the sites were examined in 2002 through 2004. The initial effects of the burn (2002-2003) on the shrub and herbaceous species response have been examined, and the three-year data are being analyzed and will be described in Jessica Dhaemer's thesis and one or more publications. Effects of community type were examined on the paired burn and control plots at three elevations (2073 and 2103; 2195 and 2225; 2347 m); influence of stand cover (low= 20%; intermediate= 38%; high= 78%) was examined at the 2195 and 2225 m elevation.

The cover and biomass of herbaceous understory species increased with elevation on both burn and control plots. The 2103 m plots had consistently lower values than 2347 m plots ($P = 0.0002$; 3-6% cover versus > 13% cover). This was because higher elevation plots had both higher precipitation and deeper soils. Herbaceous biomass increased with elevation following the burn (12.43±1.95, 50.50±15.34, and 103.70±4.31 g/m2, respectively), with proportionately greater increases occurring on higher elevation plots ($P = 0.0003$). Tree cover significantly influenced herbaceous understory. Intermediate and low tree cover plots had higher herbaceous cover and biomass than high cover plots ($P = 0.0273$, $P = 0.0286$ respectively), and these differences persisted on the burn plots.

Results indicate that high elevation sites exhibit a higher initial response of herbaceous species to prescribed fire than lower elevation sites due to higher precipitation and deeper soils. Also, sites with high tree cover have a low understory response, due to low incidence of herbaceous species prior to fire and the potential for higher soil temperatures in locations where duff is completely consumed. Prescribed fire will be most effective on sites with low to intermediate tree covers, and initial recovery will occur most rapidly on higher elevation sites. These preliminary data indicate that a threshold for unassisted recovery of herbaceous understory species exists between intermediate and high tree covers. Data collected in 2003 and 2004 will be used to develop criteria for assessing recovery thresholds over the elevational gradients that exist in these pinyon-juniper woodlands. This information will be useful when prioritizing management options for the woodlands and their associated sagebrush ecosystems. Landscapes suitable for prescribed fire or fire surrogate treatments can be selected based on their potential for unassisted recovery. Similarly, the need for rehabilitation seeding following either tree removal treatments or wildfires can be determined. This will facilitate proactive management of these valuable ecosystems.



Effect of Elevation



Effect of Tree Density

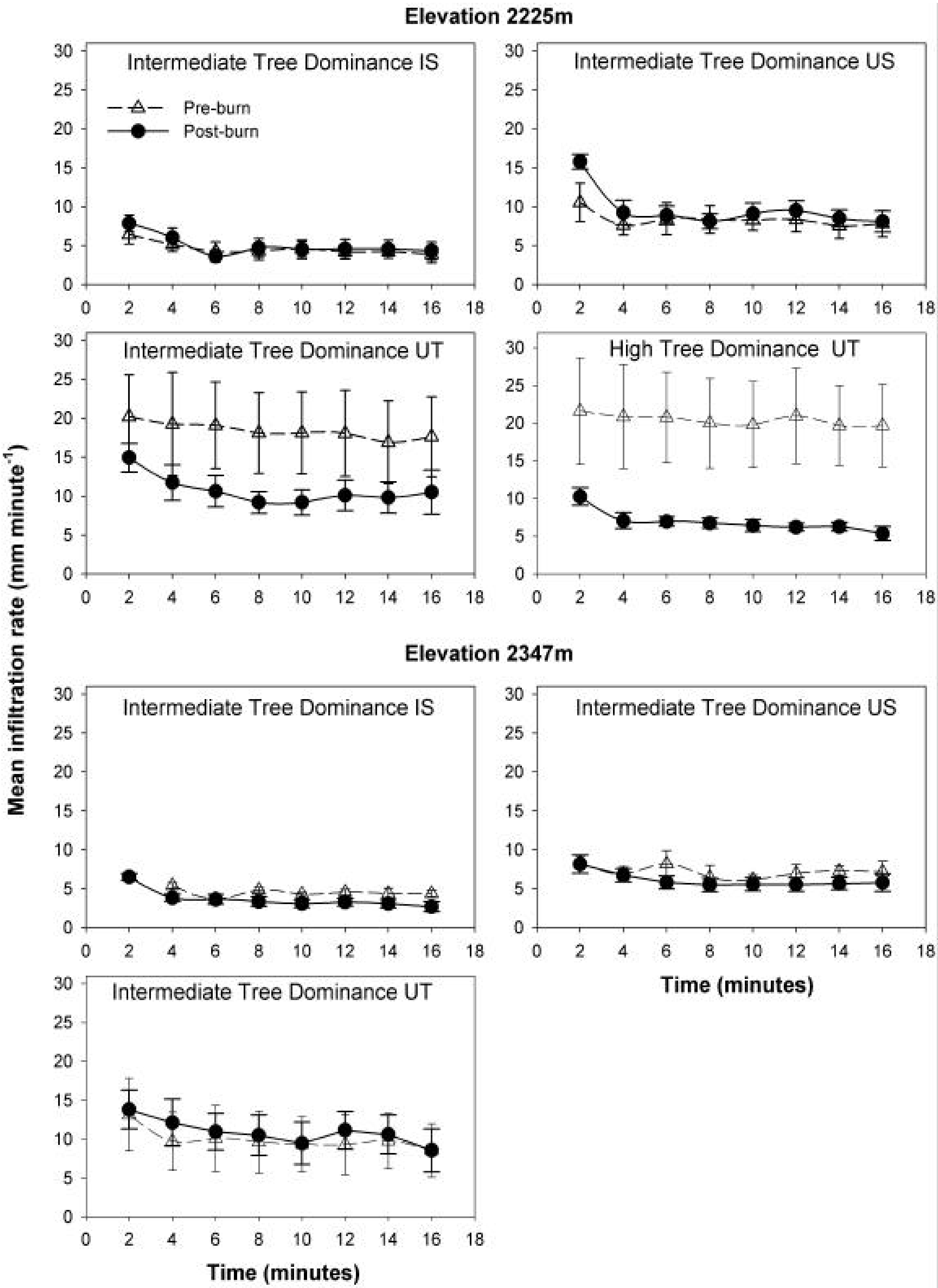
Effects of Elevation and Stand Density on Soil Response to Fire

The effects of elevation and stand density on both soil infiltration rates and soil chemical properties were examined. Manuscripts have been submitted to the Journal of Range

Management and the Soil Science Society of America Journal, and both studies will be a part of Ben Rau's Master's thesis. Infiltration rates were measured using a single ring infiltrometer over the elevation (low, mid, and high) gradient, at three microsites (under tree, under shrub, and interspace) before the prescribed burn in Aug. 2001 and then following the prescribed burn in Aug. 2002. The infiltration data were used to calculate saturated hydraulic conductivity ($K(\theta_s)$). Soil was collected from the burn location and water drop penetration times were performed in order to determine the development of water repellent soils. Final infiltration rates before the burn were higher at the low elevation than at the mid and high elevation sites, although the data could not be analyzed statistically due to the inability to pond water on the soil surface at the low elevation. The mid elevation interspace and under shrub microsites did not differ before the burn in terms of final infiltration rate or $K(\theta_s)$, but were lower than under tree microsites. After the burn no significant differences were found between microsites for final infiltration rate or $K(\theta_s)$. Interspace and under shrub microsites had lower final infiltration rates at the high elevation site than under tree microsites before the burn, and burning caused no significant deviation in this trend. Saturated hydraulic conductivity at the high elevation did not differ by microsite before the burn, however, after burning interspace microsites had lower $K(\theta_s)$ than under tree microsites. Burning increased water repellency of surface soils (0-3 cm) at the high elevation by 300% under shrubs and 196% under trees.

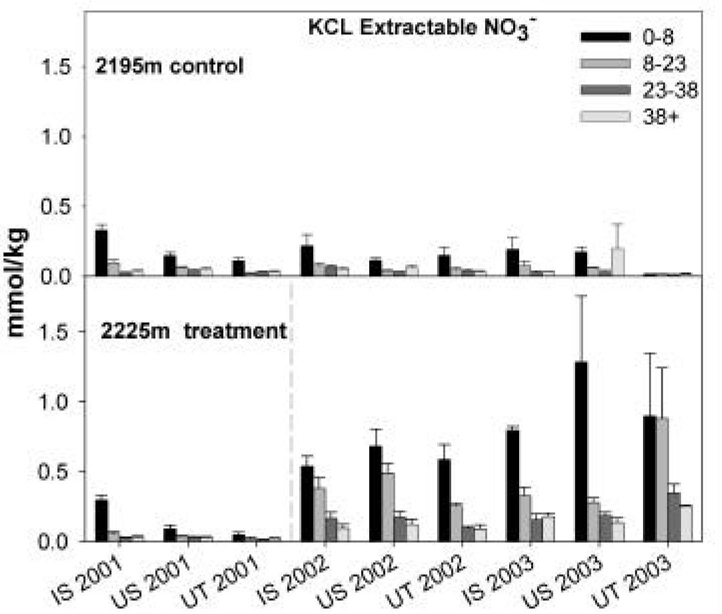
This study and others (Hester et al. 1997) indicate that prescribed burning in pinyon-juniper woodlands can affect soil hydrologic characteristics. Fire induced water repellency can be spatially variable after prescribed burning, and it is therefore important that managers consider the soil characteristics, cover type, % cover, and climate of the woodland with which they are dealing. Development of water repellent soils is affected by an elevation gradient due to differences in surface soil particle size distribution, especially coarse fragment. Water repellency also is affected by spatial variability in surface and soil organic matter based on surface vegetation and % cover. Burning of sagebrush microsites had little or no effect on surface soil hydrology if the surface soil coarse fragment was < 70%. However, burning of pinyon-juniper microsites resulted in significant decreases in infiltration and $K(\theta_s)$ if the surface soil coarse fragment was > 40%. This may indicate general responses for sagebrush-dominated vs. pinyon-juniper dominated systems. However, the effects of reduced infiltration, $K(\theta_s)$, and the development of water repellency must be considered in the context within which they occur. Soil with coarse fragment > 40% will most likely have high infiltration rates and $K(\theta_s)$. The probability of a precipitation event exceeding $K(\theta_s)$ decreases as $K(\theta_s)$ increases within a climatic region. It must also be noted that heat induced water repellency can be short lived, and broken down by light intensity precipitation and spring wetting (Morris 1987; McNabb 1989).

Alluvial fans of Underdown canyon in central Nevada are high in coarse fragment, and precipitation occurs dominantly as winter snow and spring rain. High intensity summer monsoon events are infrequent in contrast to areas in Colorado, Arizona, and New Mexico. Saturated hydraulic conductivity data collected from this site and data from NOAA indicates that a five-minute storm event intense enough to exceed the lowest levels of conductivity occurs on an interval greater than one thousand years. It is therefore unlikely that prescribed fire in an area similar to Underdown Canyon will cause a detrimental hydrologic response.



**Burn Effects on Mean Infiltration Rates (mm minute-1)
at the Intermediate and High Elevation Sites**

The effects of pinyon-juniper woodland expansion and prescribed fire on soil chemical characteristics were quantified at the mid elevation plots for three microsites (under tree, under shrub, and shrub interspace). Soils were sampled in November of 2001 to determine spatial variability in pre-burn soil nutrient characteristics. Additional soil samples were taken two days before and two days after the burn in May 2002 to determine immediate fire effects. Soils also were sampled in November of 2002 and 2003 to determine temporal and extended burn effects on soils. Fire resulted in immediate increases in soil pH, ortho-P, NH_4^+, Ca^{2+}, Mg^{2+}, Mn^{2+}, and Zn^{2+}. Immediate losses of NO_3^- also occurred. Chemical changes persisted into November 2003 with the exception of Ca^{2+}. Also large increases in available NO_3^- occurred in November 2003.



Site and Fire Effects on Nitrate

These results allow a few general conclusions about the spatial heterogeneity of soils in pinyon-juniper woodlands and their associated sagebrush semi-desert communities. Nutrient availability can change over short distances due to inherent site characteristics that affect soil development such as parent material, shading, minor variation in precipitation or snow cover, and vegetation cover. Also, vegetation type influences nutrient distribution on the landscape, and although shrubs and trees display similar characteristics for nutrient cycling, changes in percent cover of either of these components may affect watershed scale soil nutrient cycling and shift the distribution of nutrients contained in above ground biomass. Soil nutrients also vary with depth. Nutrient concentrations generally decrease with depth with the exception of Na^+, which increases with depth. The distribution of these nutrients within the soil profile is controlled by litter fall, decomposition, microbial immobilization, exchange mechanisms, and climate.

The temporal comparison of the control site indicates that soil nutrients change annually, but the variation is nutrient specific and may be affected by climatic variables. It is possible that climatic variables influence nutrient availability through mineral weathering and decomposition, or that climate influences vegetation which alters uptake and influences nutrient availability. Trends observed on the treatment site suggest that nutrient availability changes seasonally as well. Our data may also suggest that nutrients are correlated. An increase in available Ca^{2+} was coincident with decreasing ortho-P. Increasing Ca^{2+} may provide sites for P precipitation (Stout et al. 2003).

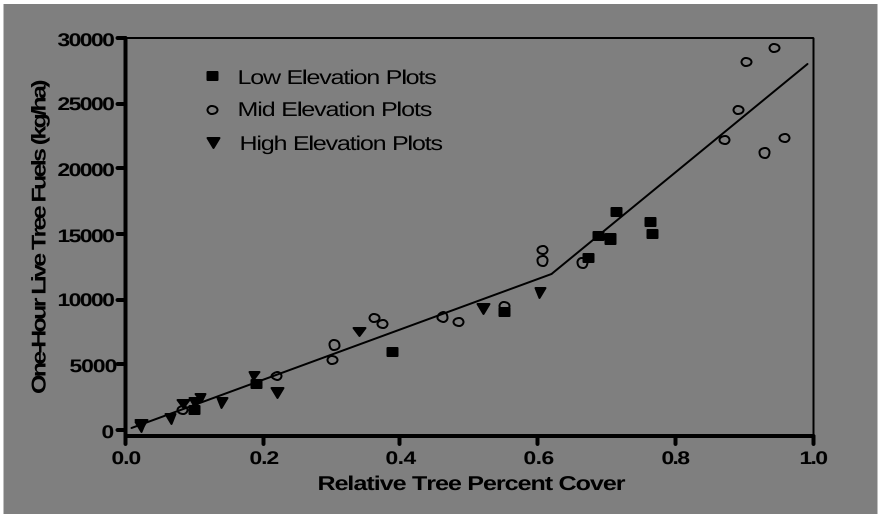
Burning had immediate positive effects on most soil extractable nutrients and pH with the exception of decreased NO_3^- and Na^+. The initial effects of burning were limited to the surface 3 cm of soil due to high fuel and soil moisture at the time of the burn, and the effects of burning were observed at all microsites. It is noteworthy that the micronutrients Mn^{2+} and Zn^{2+} respond to burning. This has rarely been observed or reported in previous literature, and may prove to be important for enzymatic processes during photosynthesis and DNA replication (Marschner 1999).

Changes in Fuel Loads with Increasing Stand Density

To determine fuel loads for the Demonstration Project regression equations were developed between plant measurements and biomass. For the understory plants separate equations were developed by species for the trees, the shrubs, and most perennial grasses and forbs (Reiner 2004). Equations were developed for the fuel categories of one-hour, ten-hour, 100-hour and 1000-hour. Some rarer species were combined. For sagebrush and rabbitbrush it was necessary to separate the plants into separate categories based on the amount of dead material in the crown. This was improved both the precision and the accuracy.

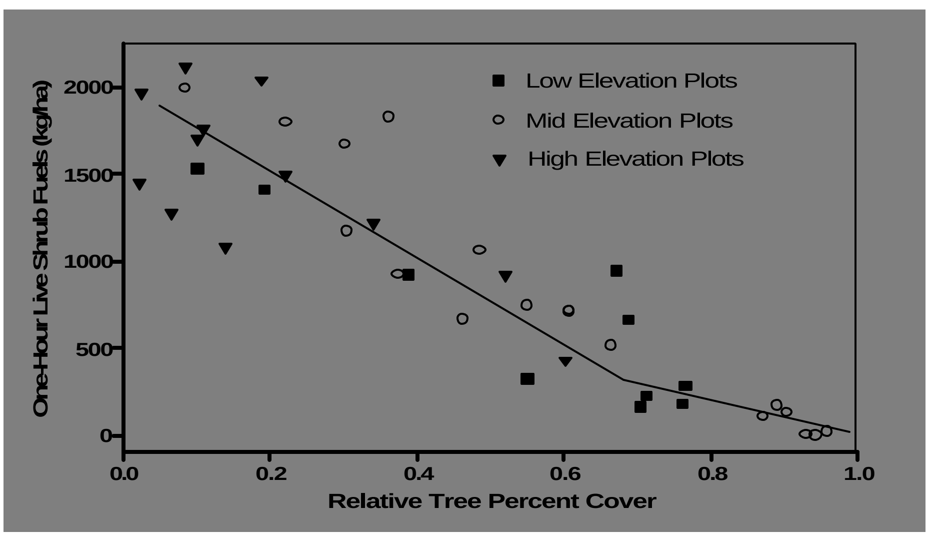
Fuel loads for the trees are based on equations developed by Tausch (in press). These equations estimated fuel loads based on the concept of a Functional Volume which is computed from crown measurements. This procedure provides improved accurarcy and precision compared to previously used methods by providing equations that are usable over a wider range of site conditions.

Using the developed equations a total of 40 plots covering the elevation range of the project were used to assess the variation in fuel loads resulting from variation in tree dominance and elevation. Results for the one-hour live fuels are used to illustrate the differences. The measure of tree dominance used for these comparisons is relative tree cover (tree cover / total cover). The pattern of increase in the one-hour live fuels for the trees was not influenced by differences in elevation (Fig. 1). There is, however, an increase in the rate of change with increasing tree dominance after the relative tree cover has exceeded 60 percent.



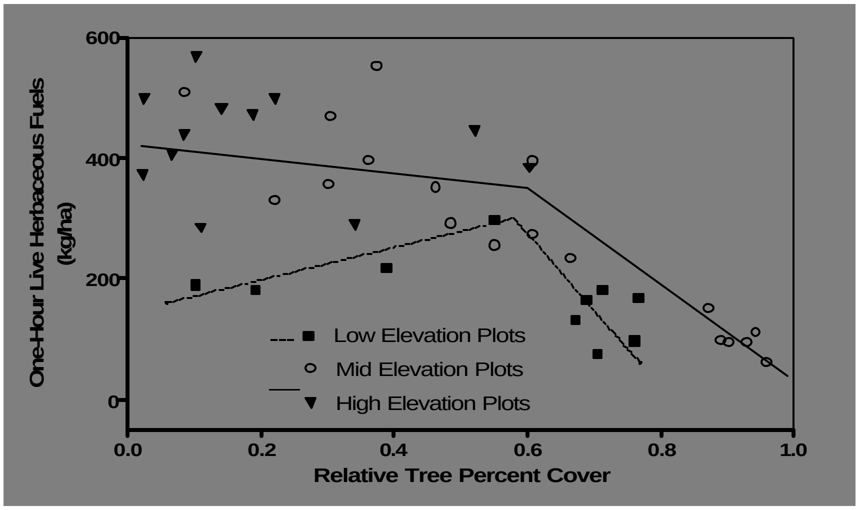
Effect of Changing Tree Dominance on Tree Live Fuels

The reason for this threshold shift in the rate of increase in tree fine fuels becomes apparent when compared with the patterns for shrub and herbaceous fuels. The one-hour fine fuels for the shrubs have a linear decline with increasing tree dominance until the relative tree cover is between 60 and 70 percent (Fig. 2). Above that level of tree dominance the rate of loss of shrub fuels nearly levels off.



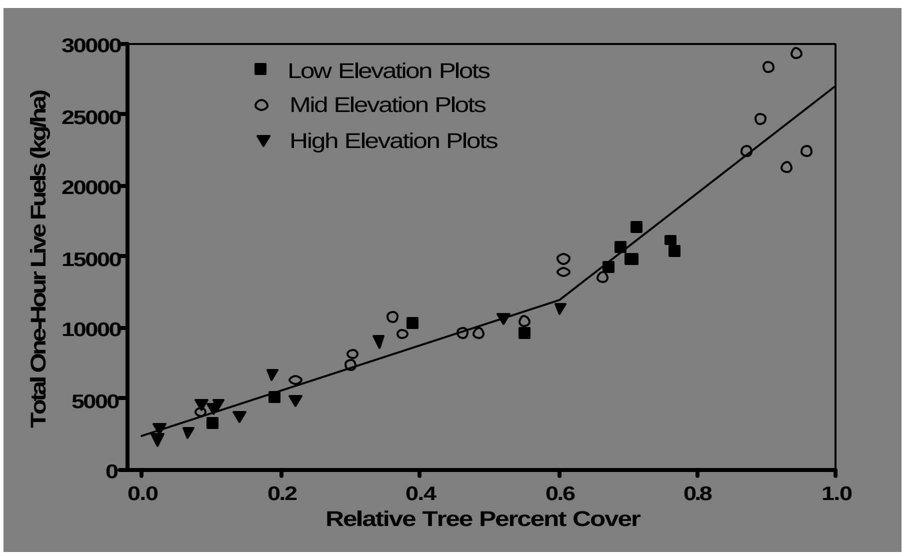
Effect of Changing Tree Dominance on Shrub Live Fuels

Changes in herbaceous fuels with increasing tree dominance differ from that for the shrubs, and also differ with elevation. The low elevation plots have both a lower amount of fine fuels, and a different pattern of response than the mid and high elevation plots (Fig. 3). The amount of fine fuel increases with increasing tree dominance up to about 60 percent relative tree cover, and then rapidly declines. On the mid the high elevation plots there is only a small decline in fuels up to 60 percent relative tree cover, again followed by a rapid decline.



Effect of Increasing Tree Dominance on Herbaceous Fuels

The pattern of change in the total fine fuels with increasing tree dominance is nearly identical to that for the tree fine fuels, varying primarily in the first third of increasing tree dominance (Fig. 4).



Effect of Increasing Tree Dominance on Total Fine Fuels

The point at which the rate of increase in the level of fine fuels contributed by the trees increases generally coincides with the loss of most of the shrub biomass. This is also the point where a rapid decline in the herbaceous fuels begins. It appears that competition with the understory has a limiting effect on the rate of increase in the trees contributed by the trees up to a level of tree dominance represented by about 60 percent relative tree cover. The ability of the trees to increase their fuel loads then appears to be released. Other data from the Demonstration Area indicate that once tree dominance exceeds the 60 percent relative tree cover the ability of the understory to respond following fire is dramatically reduced, potentially opening the site to the invasion by exotics.

There are dramatic differences in the levels of fine fuels contributed by the trees versus the understory with increasing tree dominance. At the level of tree dominance represented by 50 percent relative tree cover the fine fuels for the trees are at about one-third their eventual maximum at full tree dominance. At the same point fine fuels for the shrubs have dropped to about one-third of the level present when there are no trees. At this point the fine fuels contributed by the trees represents about 90 percent of the total live one-hour fuels present. At 60 percent relative tree cover the fine fuels contributed by the trees represents about 94 percent of the total. The total fine fuels present at full tree dominance are more than ten times the total for the sagebrush community present prior to the establishment of the trees.

In the present day Great Basin at least two-thirds of the current woodlands represent post-settlement expansion. We estimate that half or more of those woodlands have reached or exceeded 60 percent relative tree dominance. Much of the rest is rapidly approaching that figure. At the current rate of growth fuel loads in these woodlands can be expected to at least double over the next 40 years. This will also be accompanied by a rapid increase in the continuity of the fuels as more and more of the landscape becomes fully tree dominated. This increase in fuel loads and fuel continuity can be expected to be accompanied by an increase in the size and intensity of wildfires.

Effects of Watershed-scale Burns on Stream Channels and Water Quality

Stream Channel Monitoring

Wildfire or controlled burns have the potential of impacting the physical characteristics of stream channels in several ways. Soil erosion, stream flow, and sediment transport may increase after fire because of increased runoff and decreased infiltration into hydrophobic soils, especially if a large runoff event occurs soon after treatment. The likelihood of soil erosion and changes in stream channels can vary significantly following burning. If hillslope runoff is increased without an increase in soil erosion, the mainstem channels may incise (Germanoski and Miller 1995). However, if hillslope erosion is increased significantly, the mainstem channels and side-valley alluvial fans may experience sediment deposition and aggradation.

The effects of the burns on the mainstem channel are being evaluated by yearly monitoring of a series of monumented cross sections. A total of 40 cross sections were monumented and surveyed in Underdown Canyon in 2001 prior to the controlled burns. Bed material samples were collected at each cross section and grain size distributions were measured and recorded. The cross sections were located above and below every burn plot, above and below every tributary, and and at other places where the channel would likely change in response to the effects of controlled burns. Cross sections extend throughout the drainage basin from the headwater area to the alluvial fan at the canyon mouth. In addition, 20 cross sections were surveyed in Riley Creek drainage basin to serve as an undisturbed control basin. Sediment samples also were collected and measured for each cross section in Riley Creek.

Every cross section was inspected for change in 2002, 2003, and 2004 and 10 cross sections were resurveyed in 2002, 2003, and 2004. The channel has not changed because the Underdown drainage basin has not experienced a significant precipitation event or significant snowpack runoff subsequent to the controlled burns.

Research in a variety of climatic and geomorphic settings indicates that the geomorphic impact of fire is variable. To gain further insight into the importance of event-sequencing on basin response to fire in the Great Basin, we compared the geomorphic responses of two different drainage basins in the Toiyabe Mountains to lightning-generated wildfires. Crow Canyon is a 2 km^2 drainage basin with approximately 600 m of relief that is underlain by quartz monzonite and granodiorite. Wall Canyon is a 17.6 km^2 drainage basin with approximately 800 m of relief that is underlain primarily by shale, limestone, phyllite and schist. Both basins were dominated by pinyon and juniper trees with an understory of sage, rabbitbrush, and desert grasses. Crow Canyon was completely burned in August 1981 and the headward 62% of Wall Canyon was burned in August 2000. In each basin, the burn intensity was categorized as "intense" (complete destruction of all ground and tree foliage, leaving only charred trunks and branches).

Despite similarities in relief, location, and burn intensity, the geomorphic impacts have been quite different. The axial drainage system in Crow Canyon was severely degraded following the 1981 wildfire. Maximum channel incision measured at 28 cross- profiles ranged from 0.6 m to 3.9 m with an average of 1.9 m. Most of the channel incision occurred in the first two years after the fire which were characterized by precipitation as much as twice the annual average. In contrast to Crow Canyon, there has been no observable or measurable geomorphic impact in the four years following the Wall Canyon fire. The years, 2001 and 2002, were typified by normal to below normal precipitation. In the four years since the fire, grasses and underbrush have been re-establishing on the hillslopes, and may mitigate significant geomorphic impact by the time the next significant hydrologic event occurs. The disparity in response to wildfire in these two watersheds suggests that the geomorphic impact of wildfire in the arid Great Basin is highly dependent upon event sequencing.

Water Quality Monitoring

Prescribed burns have the potential to alter stream flow, sediment transport, stream temperature, and water quality in treated basins. These effects can be transient or last a long time depending on the areal extent and intensity of the burns, plant community composition before and after treatment, timing, duration, and magnitude of episodic climatic events in relation to the prescribed burns and other factors. This component of the research was designed to examine the effects of prescribed burning in pinyon-juniper woodlands and their associated sagebrush communities on stream flow, sediment transport, stream temperature and water quality. At the time that the Demonstration Area was selected for study (1999-2000), the streams in both Underdown and Riley Canyons flowed most of the year. Since that time the region has experienced below average precipitation, and the streams have flowed only intermittently in the upper parts of the drainages. Consequently, it was possible to monitor the hydrologic characteristics and water quality of the streams only in 1999. If stream flows increase within the next few years, hydrologic data and water quality samples again will be collected at the upper, middle and lower watershed segments and for major spring systems in both Underdown and Riley Canyons. Hydrologic measures include water level (measured with aquarods), stream flow (velocity-area), and bedload (sampled with a Helley-Smith sampler). Water quality measures include field determination of turbidity, temperature and pH. Laboratory measures of water quality include suspended sediment, bioavailable and total P, Na, K, Mg, Ca, alkalinity, Si, NH_4-N, NO_2+NO_3-N, total N, o-PO_4, total P, S, F, Cl, and trace elements. In addition, the streambed sediment and streambank soil would be analyzed for particle size, the different forms of carbon, total N, exchangeable cations, metal oxides and the different forms of P. This effort is complementary to a ten-year monitoring effort of water quality in streams of the central Great Basin (Amacher et al. 2004).

Effects of Watershed-scale Burns on Butterfly Species Richness and Occurrence

Human land uses, climate change, and invasive species are modifying ecosystem processes, species distributions, and population dynamics of native species in the Intermountain West and around the world. Understanding how assemblages of native plants and animals respond to these environmental changes is critical to development of effective, practical strategies for ecological restoration and maintenance. Yet the trinity of time, money, and information is elusive for land managers. Knowledge of the extent to which measures of biological diversity vary in space and time not only when treatments like prescribed fire are applied but also in the absence of deterministic treatments is essential for making accurate inferences and taking appropriate management action, especially when the consequences of those actions may be irreversible.

Butterflies are well-known ecologically, relatively easy to study and monitor, and popular with the general public. In addition, various measures of the species diversity or occurrence of butterflies frequently have been proposed as surrogate measures of the status of other taxonomic groups and of environmental variables. Although the individual and cumulative acreage of prescribed burns in the demonstration area prior to 2004 did not allow us to assess directly the response of butterflies to watershed-scale burns, the project afforded an excellent opportunity to elucidate deterministic and stochastic influences on patterns of species richness and composition of butterflies, dependence of those patterns on temporal and spatial scale, and practical sampling approaches most likely to provide valid inferences about ecological responses to an array of environmental changes, including but not limited to prescribed fire.

This component of the project has resulted in a Master's thesis and numerous peer-reviewed journal articles. It has taken three approaches to identify patterns and trends of butterfly diversity in the demonstration area, and in the landscape within which the demonstration area is embedded. It also has examined how dynamic measures of diversity affect interpretation of ecological data in the context of land management. First, nested subsets analyses have been used to determine whether the composition of local assemblages is predictable and to identify abiotic and biotic factors that may be associated with the order in which species are likely to appear and disappear. Second, the probability of detecting faunal responses to deterministic environmental changes over time has been addressed. And third, extensive work has been conducted on the effects of sampling resolution and proximity of sampling locations on inferences about species richness and turnover.

One of the major findings is that considerable variation exists in species composition across space and time. At the finest sampling resolution (site level, approximately 2–44 ha), for example, mean similarity of species composition of butterflies was 0.397; at the mountain range level, mean similarity was 0.875 (Mac Nally et al. 2004). As a consequence, the work suggests strongly that spatially extensive sampling may be a more effective strategy for drawing inferences about regional species composition than concentrating an equal amount of sampling effort on small, isolated sites scattered across the landscape. Similarly, recent work has shown that even after accounting for differences in detection probability, annual site-level turnover rates of many species of butterflies in the central Great Basin are as high as 50%. Despite considerable turnover in species composition, however, species richness of butterflies in our study system has tended to be relatively consistent between years, especially at the landscape level (Fleishman and Mac Nally 2003). Brown et al. (2001) similarly found that species richness of birds in northern Michigan and rodents in the Chihuahuan Desert remained fairly constant over the long term (22 years and 50 years, respectively) despite substantial changes in species composition, climate, and other environmental conditions.

Research conducted as part of the demonstration project, and the continued work in the Intermountain western United States, suggests that integrating studies of biodiversity patterns with examination of how study design itself affects ecological inferences may be one of the most productive avenues for developing adaptive management strategies that will conserve both biodiversity and the processes that sustain it.

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PROJECT PRODUCTS (JFSP Project # 00-2-15 & #01B-3-3-01)

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Significant Consultations

Humboldt-Toiyabe National Forest, Forest Supervisors Office, Bridgeport District, Ely District (2003, 2004). Field visits and guidelines for selecting areas within pinyon-juniper woodlands for prescribed burns and other fuels management treatments.

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